

Modernization in the National Weather Service River and Flood Program

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ABSTRACT

Hydrologic forecasting is vital not only to the National Weather Service mission of saving lives and protecting property but also to our nation's water management decision makers. Since its inception, the River and Flood Program has continually endeavored to modernize its tools and techniques. Modernization is an innovative process of research and development that strives to make available the best methods, data, and equipment for hydrologic forecasts. This paper addresses the role of modern technology (e.g., automation, computers, and radar) in hydrologic forecasting and also examines some of the problems of river modeling and forecasting and what modernization tools are available to remedy them. In addition, this paper looks at the increasing importance of training personnel to effectively use these modernized methods, procedures, and equipment in their jobs.

1. Introduction

Through the years, modernization of data observation, data collection, forecast preparation, and dissemination based on technological advances has introduced many improvements into the hydrologic programs of the National Weather Service (NWS). These programs are necessary not only to save lives and reduce flood damages but to provide the critical information to water resource managers faced with drought conditions. Proper management of water resources is essential to the nation's economy, quality of the environment, and overall social well-being.

Increased water demands, pollution, and climate variability have at one time or another made water a scarce resource in most areas. These factors constantly stress our nation's water resources systems and challenge our water management decision makers daily. Due to the vastness of our nation, some areas experience severe water shortages, while at the same time others have serious flooding. Industries and utilities must continually determine the volume of effluent that can be discharged into waterways without adversely affecting water quality and endangering fish. Reservoirs are constantly operated with the competing objectives of providing flood control, water supply, and hydro-power generation while maintaining or improving water quality, navigation, and recreation. Figure 1 shows how these objectives compete with one another by

seeking to raise or lower the reservoir pool level and to hold or release water. In many cases, water management decisions are based on localized, ad hoc information systems that are too inefficient to economize our nation's water resources.

Modernization activities in the hydrologic program, including research and development, have advanced the science of real-time forecasting and the supporting computer and telecommunications systems of data processing. This technology, together with the appropriate training of its users, has resulted in improved data available to hydrologic forecasters and our nation's water managers.

2. Activities of the modernized National Weather Service

Technology is applied to the modernized hydrologic effort; manual interaction and forecast adjustments with the technology are key elements. The NWS modernization is complemented with several components of new hydrologic software technologies, such as the next-generation National Weather Service River Forecast System (NWSRFS) and the Water Resources Forecasting System (WARFS), including an advanced version of the Extended Streamflow Prediction (ESP) system. In support of these transition activities, Prototype River Forecast Center (RFC) Operational Test, Evaluation, and User Simulation (PROTEUS) risk reductions plans have been developed in preparation for implementation of the Advanced Weather Interactive Processing System (AWIPS) environment.

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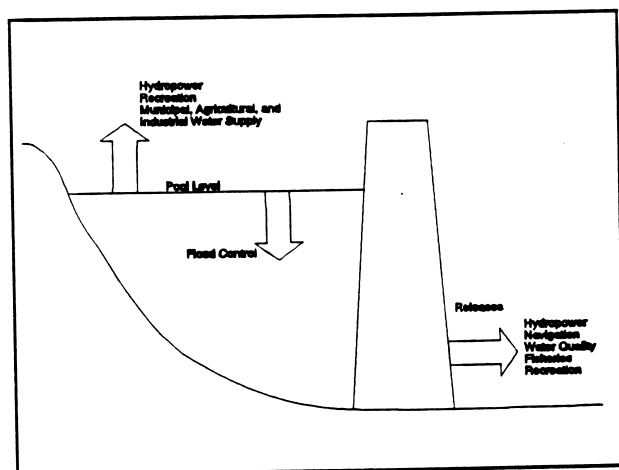


FIG. 1. Reservoir operations.

a. Forecast adjustments

NWS hydrologic forecasters use hydrologic and hydraulic modeling for flood-event modeling, simulations of seasonal and annual streamflow, and hydraulic simulation in dam-break analyses. The procedures of modeling have evolved over time from the days of paper punch cards and keypunch devices to today's microcomputers. Until recently, hydrologic modeling would not allow adjustments during a job-run cycle when simulated values clearly needed improvement. The advent of preprocessors (programs with a degree of error checking that make creating data files in the correct format easier) helped in making forecast adjustments and improving simulation results.

The fidelity of simulations are degraded by many sources. However, the forecaster's judgment and insight into the problem, with the aid of NWSRFS procedures, help mitigate the effects. The forecaster modifies the parameters and time series and then applies them to data and model parameters to define hydrologic computations at a forecast point. The forecast simulations can then be rerun with the adjustments (Wiele and Smith 1991). Some of the problems that forecasters deal with are the following.

- 1) INACCURATE REPORTS OF OBSERVED VALUES:
DATA CORRECTED BY A SET OF
MODIFICATIONS

Automatically reported river stages, for example, may have values that are clearly inconsistent with neighboring values, show no variation over a suspiciously long period of time (due possibly to a frozen gauge), or extend beyond a reasonable range. The forecaster has the option of removing suspect data or substituting correct values supplied by another source. Figure 2a shows an example from the North Central River Forecast Center in Minneapolis that illustrates

what might confront the forecaster. The stage reported automatically is obviously in error at day 23 and hour 7. It is orders of magnitude greater than the maximum flood of record at 620 cm. Removing that point and adjusting the vertical scale reveals the true hydrograph (Fig. 2b). The sharp rise at the end of the observed period is consistent with hydrographs of nearby streams and the preceding precipitation. Significant differences between simulated (projected) and observed (reliable) values can be temporarily altered on the model to account for differences between calibration and current conditions. This is illustrated in the rainfall-runoff models below.

- 2) SIMPLIFICATIONS IN CONCEPTUAL MODELS:
CORRECTED BY SHIFTING THE NOMOGRAPH
POSITION ALONG THE ORDINATE (E.G.,
CONDITIONS PRECEDING A STORM EVENT
DIFFER FROM AVERAGE CALIBRATION
CONDITIONS)

Rainfall-runoff models are used to determine surface runoff from precipitation. Some models, such as antecedent precipitation index (API) models, are calibrated for average conditions for a given time of year. Figure 3 shows part of a nomograph typical of API-type models. The family of curves represents the effect of the time of year.

- 3) INSUFFICIENT ACCURACY IN CALIBRATION:
CORRECTED BY A SET OF MODIFICATIONS
AVAILABLE IN NWSRFS THAT ALLOWS FOR
DISTORTION OF THE UNIT HYDROGRAPH TO
ACCOUNT FOR RAINFALL INTENSITY
VARIABILITIES

The translation of basin runoff to stream discharge represented by a unit hydrograph implicitly assumes uniform precipitation over the basin. Local variability of rainfall intensity, which may strongly affect response time of the stream in the individual events used to synthesize the unit hydrograph, are averaged out. Currently, forecasters depend on gauge data, which can be sparse, but, with the implementation of the Next Generation Weather Radar (NEXRAD), a more complete picture of rainfall distribution is available.

- 4) HYDROLOGIC FLOW CONDITIONS THAT
DEVIATE FROM THE NORM: ADJUSTED BY
AUTOMATIC, OBJECTIVE ANALYSIS BLENDING
PROCEDURES THAT COMBINE THE SIMULATED
AND OBSERVED STAGE

Blending procedures are used to accomplish quality control checks when data overlays fail to provide complete data fields where one source of information is lacking. Normal- or low-flow conditions require little forecast intervention. Small differences (e.g., river stage well-below flood stage) between simulated and ob-

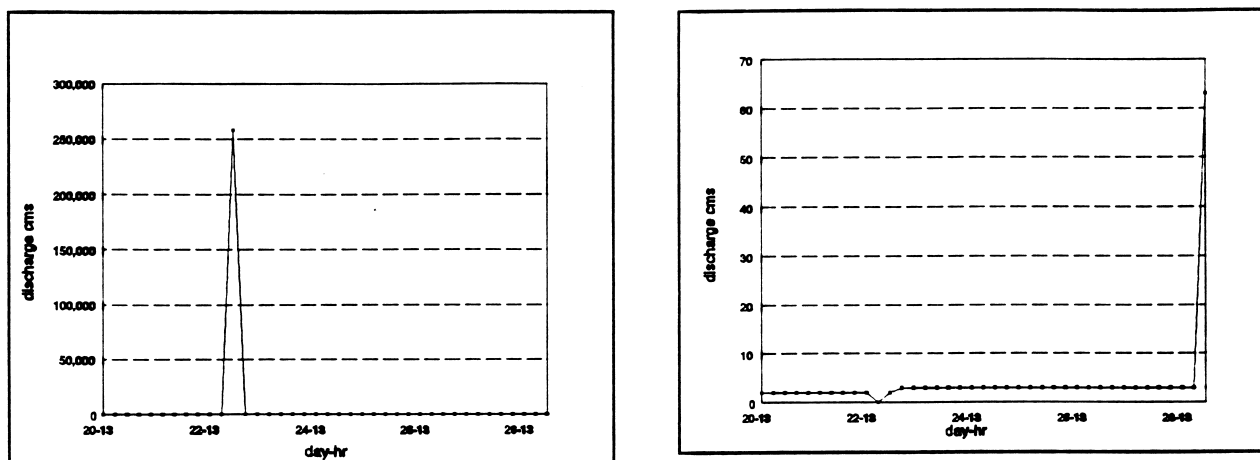


FIG. 2. (a) Discharge determined from automatically reported stages. The incorrect value at day 23, hour 7 is orders of magnitude above the maximum flood of record. (b) True hydrograph after removal of the bad value shown in (a).

served stages are of relatively little consequence unless navigability of rivers is critical. However, in near bank-full or flood conditions, simulations that show good agreement with observed stages by adjusting basic physical parameters require more forecaster analysis than may be available. One method of blending is illustrated in Fig. 4. Here the best estimate in the forecast period is determined by adding a linearly decreasing percentage of the difference between the simulated and last observed values to the subsequent simulated values.

b. Precipitation processing

The decision to replace existing weather radars initiated a major enhancement in the way hydrometeorologic data are collected. The NEXRAD program, which is responsible for deploying the Weather Surveillance Radar 1988 Doppler (WSR-88D) system,

while being on the forefront of change, will provide hourly estimates of precipitation on a 2 km \times 2 km grid across the nation. These estimates are improved significantly by ground-truth data from the following networks for its full, successful implementation: Automatic Surface Observing System (ASOS), Geostationary Operational Environmental Satellite (GOES) data collection platforms (DCP), Automated Local Evaluation in Real-Time (ALERT), Integrated Flood Observing and Warning System (IFLOWS), and AWIPS. The implementation of WSR-88D-based precipitation processing and estimation is done in three stages.

The Office of Hydrology, for the past decade, has been working on the deployment of the three stages of

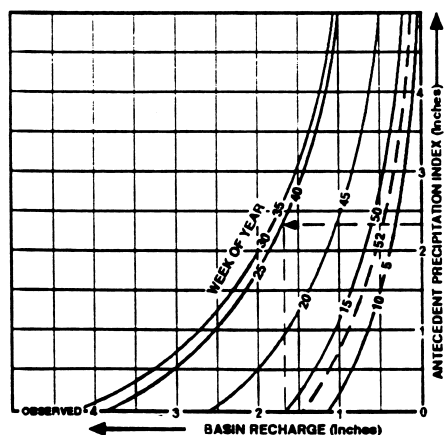


FIG. 3. Northwest quadrant of a nomograph used in Antecedent Precipitation Index rainfall-runoff models. Each curve represents conditions for a given time of year.

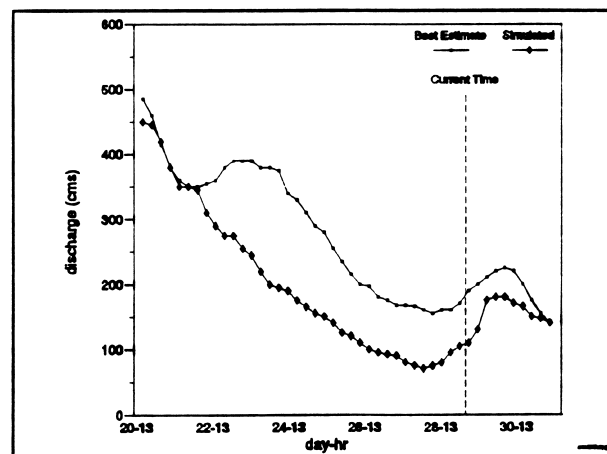


FIG. 4. Blending produces a best estimate in the forecast period based on the difference between the last observed value and the corresponding simulated value. A linearly decreasing percentage of that difference is added to the simulated value over the next eight time periods.

precipitation processing as shown in Fig. 5 (Shedd and Smith 1991).

- Stage I processing (also referred to as the NEXRAD Precipitation Processing Subsystem), run on the WSR-88D computer located at the Weather Forecast Offices (WFO). Stage I incorporates a limited amount of rain gage data in order to perform a mean field bias computation while performing a number of quality control procedures to remove errors in the radar data.

- Stage II processing, performed at the WFO on the AWIPS computer. Stage II uses additional rain gauge data as well as satellite data for quality control to produce a multisensor field merging the radar and gauge information through an objective analysis procedure and a "gauge-only" field.

- Stage III processing, run at the River Forecast Centers (RFC) mosaicking the stage II products from all the WFOs in each RFC's area of responsibility in order to develop the best possible estimate of precipitation—a flow diagram of the stage III processing features (dashed line) is found in Fig. 6. Stage III is the only stage that is interactive and, therefore, the only stage in which forecasters have any significant opportunity to interact in real-time to apply modifications and improvements that affect the precipitation field. Stage III precipitation processing software is part of the pre-AWIPS risk-reduction activity.

Forecasters have two basic quality control decisions within stage III:

- the quality of the individual stage II multisensor fields (merged fields of radar and rain gauge data complemented with satellite data for quality control purposes during stage II processing);
- the quality of the gauge data used in the stage II analysis.

An option in stage III displays the hourly gauge accumulations along with corresponding radar accu-

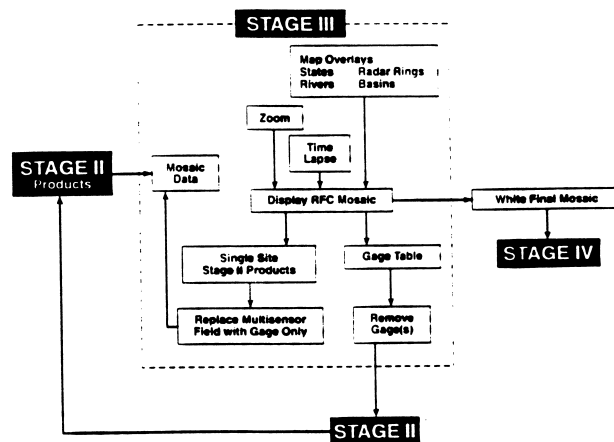


FIG. 6. Principal components of stage III processing.

mulations. Forecasters may flag a gauge or multiple gauges from a database if they believe that a gauge report is in error. Stage II runs for the affected radars are then automatically resubmitted from the RFC excluding the questioned gauge value(s) from its analysis. Following completion of stage II runs, stage III is restarted.

One principal result of these interactive quality control and analysis steps is a precipitation mosaic for the RFC area of coverage. For areas of overlapping radar coverage, the mosaicked value consists of the average of the nonzero precipitation accumulations. Earlier studies have shown this simple method to be an effective averaging scheme with a minimal computer processing load.

A daily postanalysis option is included with the stage III software to incorporate cooperative observer daily precipitation reports and to sum the hourly mosaicked fields to produce a 24-h multisensor accumulation. A gauge-only field, using cooperative network gauges, is generated using the radar to indicate the location of precipitation. Gauge data are used in the weighting to determine the quantitative estimate of precipitation at each grid location. Similar procedures for regular stage III operation are employed to verify the quality of the cooperative gauge network. Bad gauge accumulation values can be removed from the database. The multisensor and gauge-only fields then are merged to produce a final gridded mosaic for the entire RFC's area of responsibility. The merging process determines, for each grid bin, a weighted sum of the daily multisensor and gauge-only fields. The weight assigned to the gauge-only field is a function of the distance to the nearest gauge location and the spatial variability of the storm. Once a satisfactory 24-h multisensor accumulation is obtained, the daily product is time distributed (broken back down into 24-h totals) based on the hourly products previously developed to generate new hourly products for the past 24 h. This time distribution assures total water for each grid bin and produces the

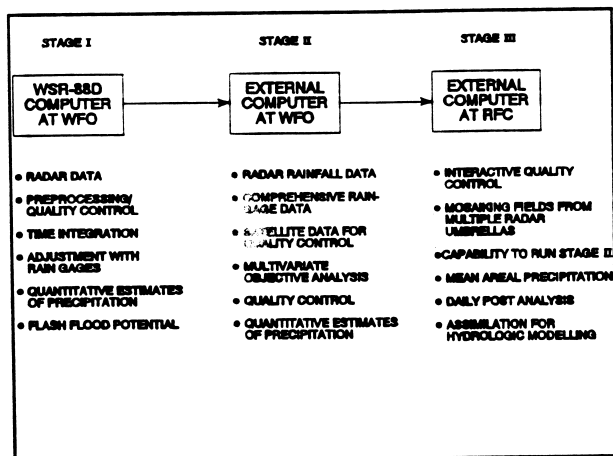


FIG. 5. NEXRAD three-stage precipitation processing.

highest quality precipitation data in the three-stage processing.

The stage III analysis produces a gridded array of precipitation, approximately 4 km per side, that varies with latitude, varies in size for each RFC, and extends somewhat beyond the boundaries of the RFC. The stage III analysis is used in two ways.

1) It is used as input to the mean areal precipitation (MAP) preprocessor of the RFCs' hydrologic models. The MAP preprocessor accumulates and averages hourly rainfall estimates to time and space resolutions required for hydrologic forecasting. The MAP time step required by the RFC may vary from 1 to 24 h. The MAP time series generated are input into the RFC hydrologic modeling.

2) It is also used as maps to be transmitted to the National Meteorological Center from each RFC where they are combined to develop a national precipitation map.

The information is provided to external users interested in water resources management. In time, a historical archive of precipitation information can be produced for use with numerous water resource programs, including the calibration of hydrologic models.

Modernized RFC staffing provides for a Hydrometeorological Analysis and Support (HAS) function, which is an integral part of its daily operations (OH January 1991). HAS specializes in the interrelated aspects of operational hydrology and meteorology in order to better forecast hydrologic events spanning a variety of timescales. The focus of the HAS function embraces assimilation of WSR-88D precipitation estimates and development or enhancement of specialized hydrometeorological techniques.

c. National Weather Service River Forecast System

1) INTERACTIVE FORECAST PROGRAM

The NWSRFS Interactive Forecast Program (IFP) consists of proven hydrologic physical process modeling of the NWSRFS combined with a graphically oriented user interface (OH Oct 1991). It provides river forecasters with the following:

- information needed to make decisions about the correctness of data or model results;
- capability to activate decisions easily and quickly to produce forecasts reflecting their best judgment about current and future hydrometeorological conditions.

There are three applications that make up the NWSRFS IFP:

- Forecaster selects the area and time period to run
- Forecaster receives an overview of current conditions.

- Forecaster looks at observed and model results and makes adjustments.

The NWSRFS consists of many programs that are used to perform all steps necessary to generate streamflow forecasts. The system includes subsystems for calibrations, for operational forecasting, and for generating longer-range probabilistic forecasts using the ESP system.

2) CALIBRATION SYSTEM

One of the major, basic improvements that modernization brings to both calibration and the Operational Forecast System is the increased run speed for even the batch versions with the powerful local processing. The faster turnaround time allows forecasters to make more adjustments and more model runs to obtain a better calibration or forecast. The calibration system performs the task needed to process historical hydrometeorological data and to estimate model parameters for specific basins (Fread et al. 1991). The models simulate snow accumulation and ablation, calculate runoff, distribute the runoff in time from within the basin to the basin outlet, and channel route the streamflow in the channels. Being a modular system, NWSRFS allows the hydrologist to select a model in a manner that is descriptive of the basin. All of the models are available for use in the calibration, operational forecast, and ESP systems. The calibration procedures involve the adjustment of model parameters for a particular basin until the simulated streamflow compares favorably, both statistically and graphically, with the observed streamflow. The ideal model parameters are those in which streamflow simulated by the model most closely match the observed streamflow.

The Interactive Calibration Program allows forecasters to easily change model parameters, run the calibration, and view the output from a graphical user interface (GUI) to the current calibration program. The improved displays (over line printer output) help the forecaster better visualize the hydrologic situation, and the GUI makes it easy to make the appropriate parameter changes and run the calibration program.

3) OPERATIONAL FORECAST SYSTEM

The Operational Forecast System contains the following three major components (Fread et al. 1991).

- Data entry program. Transfers hydrometeorological data from a variety of sources to the observed database.

- Preprocessor. Provides mean areal time series of precipitation, temperature, and potential evapotranspiration for a particular basin to the forecast component to perform hydrologic and hydraulic simulations.

- Forecast. Uses these data to model the hydrologic conditions of the basin, including the snow cover, soil

moisture, and channel storage; also updates model states by using observed data displayed with the results of the simulation to make decisions or adjustments.

Future Operational Forecast System improvements under modernization allow for use of gridded data for modeling at smaller spatial and temporal scales. In addition to improving the model forecasts, lead time is increased for forecasting fast-responding streams, and a better definition of geographic areas affected by floods is provided. Modernization also allows for storage of data (raw and processed) and parametric information in the relational database instead of the current custom databases. This should allow faster access times for data as well as additional quality control capabilities.

4) PROBABILISTIC FORECASTS

(i) *Extended streamflow prediction*

The ESP model, shown as a schematic in Fig. 7, is the portion of the NWSRFS that enables a hydrologist to make extended probabilistic forecasts of streamflow and other hydrologic variables (Day 1990). It has the following capabilities:

- allows flexibility in the streamflow variables that can be analyzed;
- makes forecasts over both short and long time periods;
- incorporates forecast meteorological data.

Because of ESP's flexibility and conceptual basis, it has many applications, including derivation of water supply forecasts, flood outlooks, and drought analyses. ESP forecast information is particularly useful during droughts. It estimates minimum streamflow, minimum reservoir level, or streamflow volume to determine if the probability level for water shortage is exceeded. The user defines water shortage risks by observing how many historical years' simulations dip below critical levels and can take appropriate measures if the risk exceeds an acceptable value for the decision maker.

ESP assumes that historical meteorological data are representative of possible future conditions. It uses these as input data to hydrologic models along with the current states of these models as they exist in the forecast component.

- A separate streamflow time series is simulated for each year of historical data using the current conditions as the starting point for each simulation. It can be analyzed for peak flows, minimum flows, and flow volumes for any future time period.
- A statistical analysis is performed using the values obtained from each year's simulation to produce a probabilistic forecast for the streamflow variable. It can be repeated for different forecast periods and additional streamflow variables of interest.
- Knowledge of the current climatology is used to subjectively weight the years of simulated streamflow

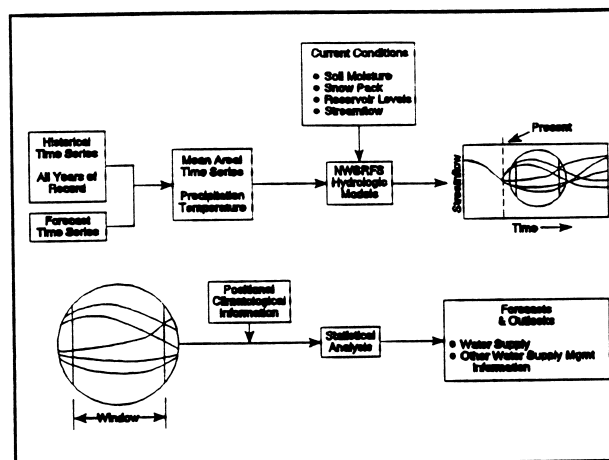


FIG. 7. The ESP procedure.

based on the similarity between the climatological conditions of each historical year and the current year.

The streamflow time series generated by ESP is input into other simulation models to investigate how water supply operations might be improved. These streamflow time series represent possible occurrences based on the current conditions and forecast data. ESP provides information for water managers to assess quantitatively the severity of the drought so that the impact of measures taken to reduce water consumption are properly evaluated against the risk of running out of water. ESP enhancements, which incorporate the National Oceanic and Atmospheric Administration's (NOAA) growing skill in short- to long-term meteorological and climatological forecasts, will enable WARFS to do the following:

- provide for analysis of streamflow trace ensembles within specified future time windows;
- objectively couple meteorological-climatological forecasts in the ensemble analysis;
- provide for a variety of probabilistic analyses of ensembles;
- package probabilistic hydrologic forecast products for future time windows out to several weeks.

Thereby, WARFS provides river forecasts that not only account for precipitation already on the ground but also probabilistically account for estimates of future precipitation.

(ii) *Water Resources Forecasting System*

Successful implementation of WARFS will improve NOAA's hydrologic prediction services (U.S. Department of Commerce 1994). The infrastructure for WARFS is the current NWSRFS, which is the heart of WARFS, shown schematically in Fig. 8. WARFS is an integrated, real-time modeling and data manage-

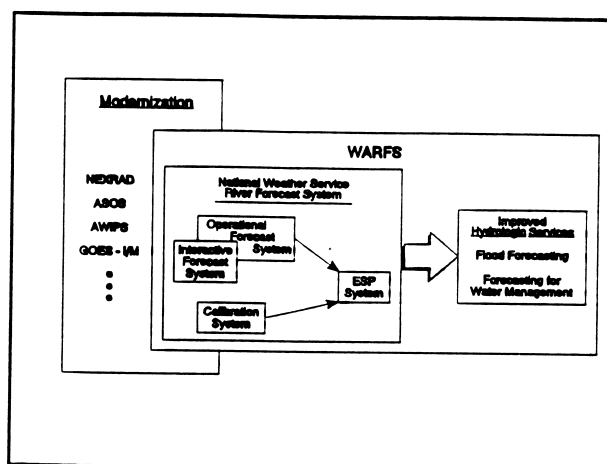


FIG. 8. WARFS and the modernized weather service.

ment and analysis system. It includes provisions for the use of historical hydrologic and hydrometeorologic data and meteorological and climatological forecasts for input to ESP simulation. WARFS long-range probabilistic forecasts greatly improve the capability of emergency managers and water facility managers to take timely and effective actions to mitigate the impact of major flood and drought situations. They also provide better support for overall water resources management (e.g., better management of competing water demands between irrigation, fisheries, and hydro-power).

WARFS takes advantage of both hardware and software components of the NWS modernization programs, including WSR-88D, ASOS, and AWIPS, providing much of the technology to observe nationwide precipitation amounts at the temporal and spatial resolution required. The advanced models, data integration, and expanded historical and real-time hydrometeorological databases with WARFS provide a strong technological base for comprehensive water resources forecasts. These forecasts, on a routine basis, provide support for day-to-day operations of water facilities as well as hydrologic information in times of special needs, such as floods and droughts.

3. Risk reduction and prototype

Risk reduction in support of the transition for the AWIPS environment is a critical and ongoing process throughout the modernization and restructuring of the NWS (OH January 1990). The AWIPS system will provide a modern, interactive processing environment that is the center of all forecast operations in an office. The PROTEUS system is a scientific workstation network that is used to execute software routines, which are prototypes to those of AWIPS. PROTEUS is a hydrometeorological risk-reduction activity, under way at the Office of Hydrology and six RFCs throughout

the nation, to identify and reduce problems associated with implementation of new RFC hydrometeorological operations in the AWIPS area. As new technologies, techniques, and models are designed and developed, they are routinely sent to the field for test and evaluation. Modifications are made before deployment to rectify any problems that develop in the field test.

Technical progress in observing systems, data-integration techniques, improved models, and expanded historical and real-time hydrometeorological databases provides a strong technological base for providing comprehensive water resources forecast information. These complex data and software systems are only effective, however, if they are used with efficient interaction by the hydrometeorologist. Interactive processing plays an extremely important role in historical data analysis, model parameter estimation, real-time data quality control, precipitation field estimation, and hydrologic forecasting.

4. Training

The requirement for up-to-date hydrologic and hydrometeorologic training is much greater in the modernized NWS than it has been in the past. Future training must account for the knowledge, skills, and abilities of the present, as well as future work force, advancements in forecasting and modeling systems, and new technologies that are being implemented. These changes are bringing new and more complex duties that require special knowledge and skills. For some duties, new positions are being created. As a result, many new career opportunities exist for entry and advancement in the modernized NWS hydrology program. The NWS is establishing a Hydrologic Intern Program that formally institutes the process for individuals to progress to journeyman-level positions in the NWS hydrology program at both RFCs and WFOs.

Appropriate university education that provides new entries into the NWS work force with a strong hydrometeorological foundation is necessary in modernized NWS operations. The hydrology program has scheduled 16 types of in-house training to meet hydrology and hydrometeorology qualification requirements. It also includes cross-disciplinary education in meteorology for those future employees majoring in hydrology-related disciplines, as well as hydrology for those majoring in meteorology (OH January 1991). These instruction areas include training for operational use of ASOS, AWIPS, and WSR-88D; the Cooperative Program for Operational Meteorology Education and Training hydrometeorology course; and other related courses. Other types of specialty training, such as computer programming, GIS exports, and system analysis, may be obtained through symposiums, workshops, and university courses to meet the requirements of various positions involved with hydrometeorologic operations.

5. Summary

The main goal of the NWS modernization effort is to improve meteorologic and hydrologic forecast and warning services. The NWS modernization and associated restructuring (MAR) is a carefully orchestrated endeavor to train its scientists and upgrade technology for a better hydrometeorological understanding of the atmosphere. Advances in NOAA's operational atmospheric prediction system will immediately improve forecasts ranging from a few minutes to several months. The improved observations and predictions are directed to mitigating the adverse effects of the environment on our nation's ecosystems, people, infrastructure, and economic projects.

Even in its early stages, the MAR is paying large dividends. Studies indicate that warnings improved dramatically when the WSR-88D was in operation (Polger et al. 1994). Specifically, the probability of detection of severe weather events increased and the number of false alarms decreased. There was also a marked improvement in the lead-time for all severe local storm and flash flood events.

In 1991, the NWS and Denver Water jointly set up the WARFS demonstration project with the goal of "Demonstrat[ing] the value of ESP forecasting for the purpose of improving water management of complex reservoir systems, and provid[ing] the basis for the planning and preparation of the national program" (Riverside 1994). This study concluded that ESP is a valuable tool in the use of operational decision support systems for water management. Substantial benefits were obtainable in the form of increased water supply and hydropower revenue and reduced risk of flooding and reservoir spill using ESP forecast information.

Other MAR benefits for the River and Flood Program include the following:

- increasing flash flood guidance from one to three times per week to several times per day;
- restructuring flash flood guidance from counties or forecast zones to grid points;
- increasing routine short-range forecasts from once per day with relatively few forecast points to at least twice per day with a greatly increased number of forecast points;
- increasing daily forecast values to 6-h forecast values where needed;

- producing text guidance products, now produced at some RFCs, at all RFCs by HAS forecasters;
- forecasting new data, QPF, and model forecasts as it is received by interactive forecast capabilities, breaking away from the traditional scheduling of forecast runs and improving forecast accuracy and timeliness.

The benefits of the MAR are manifold for the River and Flood Program and are only limited by our understanding of the new technology and our imagination and creativity to apply these new discoveries to the atmospheric sciences.

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